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6297261002

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LAUNCH ANALYSER WITH REAL-TIME ADAPTIVE CORRECTION

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LAUNCH ANALYSER WITH REAL-TIME ADAPTIVE CORRECTION

TECHNICAL FIELD

This invention relates to apparatus for measuring parameters relating to the motion of a moving article and, in particular, apparatus for measuring and recording the initial velocity and spin of a golf ball, predicting from the initial velocity and spin data the subsequent carry and runof the ball, measuring the final outcome of the golf shot and using the measured data to correct the launch measurements and shot prediction model calibration parameters.

BACKGROUND ART

Most contemporary commercial ball launch analysers use time-elapsed photography to record and analyse the initial velocity and/or spin of a ball. One or more cameras capture images of the ball at two or more instances in time after initial launch and the velocity and spin of the ball are calculated from the relative positions and orientations of the ball images at two known instants in time.

The velocity and spin sensing method as outlined above has been established practice for many years. US Pat. No. 4.063,259 issued in 1977 is one early prior art document describing the use of a still camera with electronically controlled shutter and two or more electronically controlled flash lamps, the above being arranged to obtain images of a ball at two instants of time shortly after impact to provide measurements of ball speed, launch angle and spin rate. More recently, prior art such as US Pat. No. 6,390,934 issued in 2002, describes the use of digital cameras and image processing software to automate and enhance the measurement of ball launch conditions.

An indirect way of measuring the spin magnitude and spin axis of a golf ball is disclosed in GB Pat. No. 2334781, granted in 2002, where only the ball velocity vectors are measured and the ball spin vectors are deduced from measurement of the club head velocity, its position and its orientation at impact.

Knowing the characteristics of a ball, its launch velocity and spin vectors (as measured by the above inventions) can be used to predict the final outcome of the shot. However, the accuracy of such prediction is very prone to errors arising from inaccuracies in the flight model, inaccuracies in the launch measurements, variations in atmospheric conditions (e.g. wind speed, rain effects, temperature and pressure) and variations in bounce and roll characteristics of the terrain.

The present invention aims to provide improved methods of measuring ball launch parameters by additionally sensing the final outcome (i.e. distance and direction from tee to final ball position) of at least a proportion of shots in order to reduce systematic errors in the launch measurements and shot predictions.

According to a first aspect of the invention, there is provided apparatus for measuring parameters relating to the motion of a moving article, the apparatus comprising one or more light sources for providing light from at least one reflecting zone of known shape or pattern on the moving article and co-acting light sensors arranged to provide a signal when it is illuminated by said light, wherein at least one light source and co-acting light sensor subtend an angle of less than 5 degrees at the said reflecting zone and common parts of the fields of view of the light source and co-acting light sensor define at least one detection plane across the path of the reflecting zone and at least one of the light sensors is arranged to sense variations in the said signal when the reflecting zone intercepts a given detection plane wherever the reflecting zone intercepts the detection plane and light reflected by different parts of the said shape or pattern is detected as the reflecting zone passes through the detection plane, the arrangement being such that the position and orientation of the detection plane relative to a reference frame is known and the time dependent displacement of the reflecting zone normal to the detection plane and the orientation of the reflecting zone about an axis within that detection plane can be determined from said signal.

According to a further aspect of the invention, the apparatus is provided in combination with one or more articles the movement of which is to be sensed, the, or each of the articles being provided with a retroreflective zone and/or diffusely reflecting zone. The said retroreflective zone may be provided with special prism structures with biased and/or variable tilt axes in order to orientate the

maximum reflectivity at an incidence angle other than 90 degrees and/or make the reflectivity more uniform over a range of incidence angles.

The article may comprise a golf ball and, according to a further aspect of the invention, there is provided a golf ball for use with the apparatus, the golf ball may be provided with at least one retroreflective zone with the remainder of the golf ball surface providing a diffusely reflective zone.

The article may comprise a golf club and, according to a further aspect of the invention, there is provided a golf club for use with the apparatus, the golf club being provided with at least one retroreflective region preferably on the clubhead and/or on the lower end of the shaft, above the club head.

According to a further aspect of the invention, the apparatus is provided in combination with additional sensing means to measure the final outcomes of at least a proportion of golf shots and such measurements are used to correct the ball launch calibration parameters and/or the prediction of ball carry, bounce and roll, taking into account prevailing atmospheric conditions and prevailing bounce and roll characteristics of the terrain. In a preferred embodiment, the said sensing means comprises RFID technology with active tags embedded in each ball to identify each ball at the tee and at instrumented target areas on the driving range outfield where means is provided to interrogate RFID tags, dependant on ball position.

Preferably, one or more light sources and co-acting light sensor subtend angles at the reflecting zone of less than 2 degrees worst case, or more preferably less than 1 degree worst case, but typically 0.5 degrees or less. In this context, worst case means the maximum subtended angle corresponding to the minimum expected distance between the reflecting zone and the apparatus.

For convenience, we adopt the following nomenclature:

'Detection plane' is abbreviated to DP;

The angle subtended at the reflecting zone between a light source and its co-acting light sensor is the 'observation angle';

A light source and its co-acting light sensor is a 'TXRX pair';

The separation between the active elements in a TXRX pair (measured normal to the DP) is the 'TXRX separation'; and

The axis co-linear with the centre of the light source and the centre of the light sensor in a TXRX pair is the TXRX axis.

One means of creating a DP is to arrange the active elements in a TXRX pair in close proximity (e.g. 2 to 5 millimetres apart, but not limited to this range) and some distance behind a slit aperture. The width of the slit aperture may nominally equal the TXRX separation, with the length axis of the aperture perpendicular to the TXRX axis. Neglecting the finite size of the active areas in the TXRX pair and diffraction effects at the edges of the aperture, the width of the DP in this arrangement is nearly constant throughout the useful extent of the DP and is equal to the TXRX separation (typically 3 to 4 millimetres). This controlled width DP is advantageously used in conjunction with retroreflective reflecting zones that have much greater reflective efficiency than diffuse reflectors, with the efficiency increasing with smaller observation angles. This increased efficiency helps to compensate for spreading losses at increasing range (and thus decreasing observation angle). When the DP is not more than x millimetres in width (where x can be any number, but typically 3 to 4 millimetres), different features in the shape or pattern of the reflecting zone can be detected provided that these features are separated by at least x millimetres. By providing a line array of light sources and light sensors with adjacent elements in the array forming a TXRX pair and with the array axis normal to the length axis of the slit aperture, the position of the DP can be altered, depending on which TXRX pair is selected or made active. In this arrangement, each TXRX axis is co-linear with the said array axis.

A second means of creating a DP is to arrange that the TXRX axis is parallel to the length axis of the slit aperture. Provided the TXRX separation is small compared to the length of the slit aperture, the fields of view for the light source and light sensor are nearly identical. The DP thus formed comprises the common field of view. An advantage of this type of DP compared to the previously described DP is that more light is emitted into the DP and more light is reflected back from the DP because the entire field of view is used. However, the width of the DP increases with

range as it spreads out into a wedge shaped volume. This can be corrected using a cylindrical lens, so that the DP is again of uniform thickness (equal to the width of the slit aperture) or nearly so. This method of forming the DP improves its sensitivity and operating range.

It is sometimes desirable to use a diffuse reflecting zone (e.g. one side of the surface of a golf ball). Because diffuse reflection is inefficient, the above second method of creating DP(s) is preferred for diffuse reflection. In this case it is sometimes advantageous to have larger TXRX separation (giving greater observation angles) to enhance diffuse reflection and suppress retroreflective reflection from the same reflecting zone.

Means can be provided to enhance the detection of a retroreflective reflecting zone in the presence of spectral reflection (e.g. reflection from polished parts of the moving article) by using a first light polarizing filter between a light source and a retroreflective reflecting zone and a second light filter polarized at 90 degrees to the first polarizing filter in the path of the received reflected light. In this respect, it is useful to use visible red light TXRX pairs, since suitable polarising filters are currently more readily available in this spectrum. Alternatively, infrared light can be used where red would otherwise be distracting to the user, or a mixture of red and infrared can be used to optimise overall measurement performance and user acceptance.

Preferred shapes for the reflecting zones have simple geometries such as circular, hemi-spherical (i.e. a golf ball surface), triangular or quadrilateral. However, any shape that can be defined mathematically may be used. The DP's are preferably arranged to traverse the path of a reflection zone at various positions along the path and at various angles thereto. As a reflection zone travels through the various DP's, data capture circuits record the corresponding time and amplitude response. These data are used to compute the speed, position and direction of the reflection zone and thus determine the ball and/or clubhead motion. A powerful technique for extracting accurate three-dimensional data of the motion of a reflecting zone as it passes through an array of DP's is the Levenberg-Marquardt method for non-linear estimation. This, and alternative estimation algorithms, require a fairly representative mathematical model of the measurement system and to this end it is advantageous that the reflecting zones have basic geometries that can be described

in simple mathematical terms.

The light emission in a DP may be continuous or pulsed. In one preferred embodiment, low duty cycle pulsed emissions with a repetition frequency in the range 10 kHz to 100 kHz are used with measurements coinciding with each pulse. This corresponds to providing measurements of a clubhead and ball positions at intervals of a few millimetres to a fraction of a millimetre. (In a `full swing` golf shot the clubhead speed at impact is typically in the range 25 m/s to 55 m/s, and ball launch speeds are typically 30% to 60% greater). For applications where the movement of a golf putter is to be measured, the repetition frequency can be much lower (e.g. circa 1 kHz).

The invention will now be further described, merely by way of example, with reference to the accompanying drawings in which:

FIG. 1 is a logic block diagram of a golf range facility according to the invention;

FIG. 2 is a side elevation view of ball launch measuring apparatus according to one embodiment of the invention depicting two possible ball launch scenarios;

FIG. 3 shows a time dependent waveform representing a sensor signal generated in the arrangement of FIG. 2;

FIG. 4 shows a view along arrow A1 in FIG. 2;

FIG. 5 shows time dependent waveforms of representing sensor signals generated in the arrangement of FIG. 4;

FIGS. 6(a) to 6(f) are schematic views of typical detection plane arrangements; bbb

FIGS. 7(a) and 7(b) are schematic views of a further detection plane arrangement incorporating a cylindrical lens;

FIG. 8 shows two schematic views of a golf ball with a spherically symmetric arrangement of retroreflective elements;

FIG. 9 is a top view of ball launch measuring apparatus according to a second embodiment of the invention where both the clubhead and golf ball are measured during impact;

FIG. 10 is a side view of the club head and golf ball of FIG. 9, where the club head passes through three detection planes;

FIG. 11 shows time dependant amplitude waveforms illustrating signal responses in the detection planes of FIG. 10; and

FIGS. 12(a) and 12(b) show two arrangements of buried loops that may be used to detect and locate a golf ball containing a RFID tag.

The block diagram of FIG. 1 outlines the top level system for a golf range facility according to one aspect of the invention where several golfers hit golf balls into the same general area and sensing means are provided to predict and/or measure the outcome of every shot. Blocks representing first, second and Nth golfers using the range are show at 1,2 and 3 respectively. The golfers launch golf balls downrange into the air and onto the outfield at random times and with random distances and direction, and some of the balls finally run onto instrumented target areas 4 where their position and tag identifier can be sensed. For the purpose of system analysis, the air and target areas can be considered as a transfer function with parameters comprising earth's gravity, air temperature & pressure, wind speed & direction, surface bounce, surface roll, surface contours and other factors that can affect ball flight such as rain or snow. We assume that the balls land on horizontal, flat terrain, but departures from this that would significantly affect the run of the ball can be built into the transfer function. Preferably, all the golf balls used in the facility are of similar external construction with nominally equal weight and diameter (which is true by default for all standard golf balls), and of closely similar impact and aerodynamic properties, which again is easily achieved.

Each golfer is provided with one launch analyser and tagged golf balls 5, 6 or 7. The balls may be dispensed at or near the tee or at a central dispensing station and during the dispensing process the codes for each ball received by a golfer are read and stored in memory in a central computer 8. The launch analysers measure the initial velocity and spin vectors of the balls. The data from all the launch analysers and ball tag codes being used by each golfer or at each driving bay are transmitted to the central computer 8, which in turn relays measured or predicted data on the outcome of each shot to the appropriate video display 9, 10, or 11.

In order to sense the final position of a tagged ball that comes to rest on one of a number of target areas 4, each ball is provided with an active RF transmitter, preferably using an internal re-chargeable power source. Typically the power source may have capacity of a few milliamp-seconds or less (e.g. from charge stored in a high-value multi-layer ceramic capacitor or the like). The power source may be charged through a connector but preferably charge is provided from an inductively coupled external field prior to hitting the ball off a tee. The balls may be activated to transmit their unique code by an RF field that is local to each target area. The position of a stationary ball on a target area can then be sensed either by buried loops within operating range of the tag transponders or by directional scanning antennas located in the vicinity of each target area.

In one preferred arrangement, the RFID reader at each target area is provided with a plurality of antennas and receiver channels configured such that at least one can receive transmissions from the golf ball tag dependant on its orientation. The RFID tags may be programmed to be normally in standby (low-power mode) and momentarily power-up at two to three second intervals or other intervals so that if it is in radio range with at least one antenna/receiver circuit it can indicate its presence. The interrogation (i.e. radio communication between reader and tag) is then performed using the in-range channel. This means that only one channel performs the interrogation and that reader transmit power is only required when a ball first lands on a target area. Preferably, means may be provided on each tag to sense the high energy impact of the golf shot and initiate power-up only after impact and optionally shut down after the tag code is successfully transmitted to the target area receiver.

The instrumented target areas may comprise only a small fraction of the total outfield area so a majority of balls may come to rest in intermediate areas between the target areas. In these instances, the outcome of a golf shot is interpolated using computer prediction of the outcome based on accurately measured ball launch parameters.

The target areas measured data (i.e. final position and tag code) is used to apply corrections to the data generated in each of the launch analysers 5, 6 & 7 and to update the golf shot prediction model so that the interpolation of shot outcomes is accurate. The above corrections are generated using iterative algorithms that test where and how much correction is appropriate so after a few results from each launch analyser the predicted and actual data converge (to within very small tolerance). The correction process continues as long as golfers hit balls onto the instrumented target areas and adapts to environmental changes on an hour-to-hour and day-to-day basis. The computer can also monitor long term calibration drift in each launch analyser and elements in the ball position sensors and apply appropriate correction or report that specific components of the facility require maintenance. Optionally, wind speed and direction can be measured by a monitor 13 positioned downrange and transmitted to the central computer to assist the prediction process. By this means the results shown on the video display units 9, 10 & 11 reliably report the correct results corresponding to each golfer's actual shots, and with great precision.

The launch analyser apparatus may be provided with a card reader to allow electronic payment for use of the facility. This may be a standard credit card or a special card issued by the driving range operating company. The special card would typically provide membership account data for an individual or group customer, such as membership expiry date (if required) and credit amount for future playing time. Additional data such as a customer's e-mail address can be used to relay the results of a practice or game session direct to the customer's home PC. Alternatively, data from individual customers could be automatically posted on a website and each customer provided with a unique password to allow private access to their results.

FIG. 2 shows one form of launch analyser according to the invention. A golf ball 21 rests on a rubber tee 22. The tee 22 is semi-permanently fixed to a playing surface or play-off mat 23. Other ball placement arrangements may be adopted. For example, the ball can be placed directly on a

mat or on turf, provided that the placement spot is nominally on a known vertical axis in relation to the apparatus.

For convenience, reference axes X, Y and Z are shown in the drawings. The Z-axis is vertical and points upwards. The Y-axis is horizontal and points downrange (i.e. along the general line of flight of a golf shot). The X-axis is orthogonal to Y and Z and points in the general `heel-to-toe` direction of a clubhead at ball address.

The golf ball 21 is provided with a small retroreflective element 24 adhered to its surface. The area of the element is typically only one hundredth or so of the total ball surface area. For convenience, we refer to the retroreflective element hereinafter as the RE. The RE may be elongate and, prior to a golf shot, positioned at the top dead centre of the ball and aligned along the desired launch direction. Three DP's 25, 26 & 27 are disposed below the ball flight path. As a reflecting surface enters one or other of the DP's, an sensor signal is generated within the sensor enclosure 28. The magnitude of this signal is proportional to the amount of light reflected back to the sensor, which in turn depends on a number of factors including the reflectivity of the surface under the prevailing conditions, the angle of incidence, the range or distance of the reflecting surface to the sensor enclosure and the area of the reflecting surface within the DP. Note that the DP's 25, 26 & 27 are not 'planar' in the strict meaning but have finite thickness. In one preferred arrangement, the thickness of any DP is less than the length of a RE.

The balls are themselves diffusely reflective so a central circular area of a ball passing through a DP can be detected. Thus, three successive instants in time when the centre of a ball coincides with the true central plane in each of the DP's 25, 26 & 27 are detected. The time of impact may be sensed by a microphone or other means and, knowing the above successive instants in time and the positions and the orientations of the DP's 25, 26 & 27 relative to the tee 22, the speed and trajectory of a ball can be found.

After impact from a lofted club such as a driver or iron, the ball travels at high speed substantially along a desired azimuth direction and upwardly at an elevation angle imparted by the club loft. In

addition to linear velocity, each ball has backspin due to oblique impact, which again is due to the club loft. As a ball flies up and away from its pre-impact resting position, it rotates backwards so the RE eventually enters the downward facing hemisphere of the golf ball. Because of backspin, the peripheral speed of a ball on its lower (downward facing) surface is greater than the ball translational speed. It follows that the RE's (if facing more or less downwards) pass through DP's at greater speed than the corresponding ball centres. The arrangement is such that the RE's can be detected by at least one DP for the range of backspin rates that are to be encountered. (More than three DP's at different angles can be used to ensure correct operation.) As a RE passes through a DP, its position forward or backward from the ball centre can be detected and this can be converted to a measure of the angle of backspin rotation at the time the ball passes through the DP, which in turn gives an accurate measure of the backspin rate.

For simplicity of description, we show DP 25 angled at 45 degrees to the vertical and tilted towards the tee, DP 26 on the vertical and DP 27 angled at 45 degrees to the vertical and tilted away from the tee. In FIG. 2 we show two possible trajectories with corresponding balls 29 & 30 and RE's 31 & 32 respectively. Ball 29 exhibits high trajectory and high backspin, typical of a shot from a high-lofted iron club, and in FIG. 2 it has rotated through 240 degrees (2/3 revolution) when its centre coincides with DP 29. In this case, the centre of RE 31 (being typically 10 millimetres long) has already passed through DP 25 so the sensor signal waveform 40 (shown in FIG. 3) exhibits a high output portion 41 corresponding to the passage of RE 31 through DP 25 prior to the peak 42 of the base signal. The base signal is of lower amplitude than signal portion 41 as it corresponds to the passage of the diffusely reflecting surface of ball 29 passing through DP 25. Although the reflecting area of RE 31 is much less than the effective reflecting area of the ball, the much greater reflectivity of the retroreflective surface provides the higher strength signal. Note also that signal portion 41 magnitude varies throughout its duration, being lower in magnitude at the leading edge 43 compared to the falling edge 44. The reason for this is that, due to the curvature on the ball surface, the first end of RE 31 to enter DP 25 presents a high 'entrance angle' to the incident light beam forming DP 25, whereas the following end of RE 31 presents a much lower entrance angle. The reflectivity of retroreflective materials increase with lower entrance angles and lower observation angles.

In contrast to ball 29, ball 30 has low trajectory and relatively low backspin, typical of a higher velocity golf shot from a driver or other wood club, and rotates through 135 degrees (3/8 revolution) when its centre coincides with DP 27. In this case, the centre of RE 32 coincides with the centre of the ball at the moment that both pass through DP 27 so in the corresponding sensor signal waveform (shown at 127 in FIG. 5) the high output portion 51 coincides with the peak of the base signal. Note that the peak of signal portion 51 is much flatter than signal portion 41 (in FIG. 3) because in this instance the entrance angle is zero at the centre of RE 32 and still small at both ends of RE 32.

FIG. 4 shows the view along arrow A1 in FIG. 2. This view is on the underside of ball 30 and parallel to DP 27. An additional DP 45 (not shown in FIG. 2) is rotated about the centre axis of DP 27 (i.e. the axis defined by; X = 0, Y = OY + Z, where OY is the offset between the tee 22 and DP's 25, 26 & 27, measured along the Y-axis). Similarly, additional (but not shown) DP's rotated about axes defined by; X = 0, Y = OY - Z; and X = 0, Y = OY are associated with DP's 25 and 26 respectively. These DP's rotated in the X = 0 plane are used to detect any off-centre deviation of the ball or RE.

We show in FIG. 4 that the centre 46 of ball 30 is slightly displaced from the X = 0 plane 47 in one direction and RE 32 is also displaced from this plane but in the opposite sense. This offset between ball centre and RE is due to a component of sidespin on the ball, which tilts the spin axis off the horizontal. The degree of this offset advantageously gives a measure of the sidespin on a ball, which is an essential parameter to determine deviation in ball flight. The manner that the above displacements from the X = 0 plane affects the sensor signal waveform 145 for DP 45 relative to the waveform 127 for DP 27 is shown in the traces of FIG. 5. In FIG. 5 the origin (t = 0) corresponds to the moment of ball 30 trajectory depicted in FIGS. 2 and 4. For waveform 127, the signal responses due to the ball surface reflection and the RE 32 reflection are symmetric about t = 0, indicating that the ball 30 and RE 32 are central in DP 27. For waveform 145, the base signal peak 48 is earlier than t = 0, whereas the RE 32 response portion 49 is delayed. These relative time shifts provide a measure of the sidespin magnitude and sense.

The qualitative features of the signal waveforms of FIGS. 3 and 5 are evident, but it is not so obvious how to extract precise data from such waveforms. The preferred method is to use a guess of the ball and RE motion and apply this to a mathematical model of the array of DP's and their response to reflections off a ball and off a RE. The main features of the waveforms allow an initial approximate guess of the ball velocity, trajectory and spin from which model data are generated. The model data and real data are compared and the differences are used to obtain an improved guess (i.e. an improved estimate). We repeat this process until the model data converges to nearly the same as the real data. The above is a simplified description of well-known techniques in engineering generally known as non-linear minimisation or no-linear estimation. One preferred mathematical technique for solving the estimation is the Levenberg-Marquardt method.

To formulate the initial guess, the motion of a ball and its RE are broken down into component parts as follows. When no sidespin is present, the RE rotates about a horizontal axis normal to the line of flight and on a vertical circle of diameter equal to the ball diameter. Superimposed on this spin motion, the spin axis moves at virtually constant velocity along a line normal to the axis. With sidespin, the RE rotates about an axis at a slight tilt angle θ to the horizontal (rarely more than 20 degrees) and on a circle of diameter reduced by cos (θ) and again the spin axis moves at constant velocity along a line normal to the spin axis.

FIGS. 6(a) to 6(e) show various arrangements for forming DP's. In FIG. 6(a) a light source (TX) device 60 is separate from a light sensor (RX) device 61 by distance δ, which is preferably less than 5 millimetres. An optical shield 62 (which may also form an electrical shield) is placed between the two devices and a slit aperture 63, also of width δ, is placed in the field of operation of each device at distance L. The slit aperture 63 is elongate with its length axis normal to the page, so the arrangement forms a DP that is normal to the page. For simplicity, the active areas of each electro-optical device are assumed to be negligibly small so that light rays to or from these devices can be considered to be a point receptor and point source respectively. The light rays beyond the aperture 63 spread out in two wedge shaped volumes 64, 65 where the angle enclosed by each wedge is δ/L radians. A DP 66 is formed in the overlap between the two wedges and provided the

width between the devices 60, 61 exactly equals the width of the aperture, the DP 66 has parallel sides and is of width δ. FIG. 6(b) shows the arrangement of FIG. 6(a) in a view normal to the plane of the DP 66, where the length axis of the slit aperture is in the plane of the paper. The DP spreads out in a wide arc, limited by the ends 68, 69 of the slit aperture. In practice, diffraction effects and finite size of the active areas in the devices 60, 61 shape the width profile of the DP 66, but over a useful operating range the thickness is fairly uniform and can be fairly accurately defined for computer modelling purposes.

FIG. 6(c) shows how three DP's 70,71 & 72 (with centre planes normal to the page) are formed from one TXRX pair 73 and three slit apertures 74, 75 & 76. The widths of the slit apertures 74, 76 are slightly narrower than the width of aperture 75 to allow for the foreshortening of the TXRX separation when the operating region of the TXRX pair 73 is oblique. This reduces the quantity of transmitted and received light in DP's 70 & 72, but the relatively smaller observation angles partly compensate.

FIG. 6(d) shows how a line array comprising three light emitting devices 77, 78 & 79 and two light sensor devices 80 & 81 form four DP's 82, 83, 84 & 85. In this arrangement, the three light emitters 77, 78 & 79 operate in multiplex mode (i.e. they are switched on, one at a time in succession) so only one or two of the four DP's are operated simultaneously. This arrangement can be expanded to a greater or lesser number of DP's and is useful to scan a stationary RE to detect its exact position before it is set in motion.

FIGS. 6(e) and 6(f) show an alternative arrangement where a wider DP is preferable to detect a golf ball using diffuse reflection off most of the available surface on the golf ball. Here a light emitter device 86 and light sensor device 87 are placed on a line parallel to the length axis of a slit aperture 88. This provides a DP in wedge shape form with increasing width at increasing distance away from the devices 86,87 and thus allows a greater amount of light, compared to the constant width DP's of FIGS. 6(a) to 6(d), to illuminate and reflect back from the diffuse surface of a golf ball. In detecting the position of a golf ball, a narrow DP is not necessary and the width can advantageously increase to slightly less than the ball diameter. This still allows a true peak to form

in the sensor signal, which is detectible and corresponds to the ball centre being aligned with the central plane of the DP. By increasing the TXRX separation the observation angle is increased, which makes this type of DP less responsive to RE reflections but does not reduce its response to diffuse reflection. It is thus possible to provide one light sensor device with two multiplexed co-acting light source devices; one closely adjacent and placed on a line normal to the slit aperture axis for optimum RE response and resolution; and the other on a line parallel to the slit aperture and at greater separation for maximum 'whole ball' response and low RE response.

In FIGS. 7(a) and 7(b), a TXRX pair 90, a cylindrical lens 91 and a slit aperture 92 are arranged with the TXRX axis, the length axes of the lens, and the length axis of the slit aperture parallel and coplanar. The TXRX pair 90 is disposed on the principal focal line of the cylindrical lens such that parallel rays (show as dashed lines 93 in FIG. 7(a)) converge to a line focus on the TXRX axis. With this arrangement, a DP is formed with nominally uniform thickness 94 equal to the width of the slit aperture and with angular extent 95 determined by the length of the slit aperture and the distance of the TXRX pair behind the aperture. The advantage of this arrangement compared to that of FIG. 6 (a), is that the angular field of view 96 of the TXRX pair (behind the lens) is much wider, so more light is emitted out and reflected back. Thus, this arrangement has higher sensitivity and detection range.

In practice, it is difficult to ensure that the TXRX pair 90 is exactly placed on the principal focal line of the cylindrical lens 91. Small errors in positioning result in the DP either converging or diverging, so that the thickness reduces or increases slightly with increasing range. If necessary, this variation (which is a constant systematic error) can be measured during system calibration.

In FIG. 8 a golf ball 100 is provided with a spherically symmetric arrangement of RE's 101. Typically, each RE is inserted as a separate element within the area of one large dimple on the ball surface. The RE's may be small circular discs of micro-prism retroreflective material, or may be single-prism structures or the like. It is necessary that the means of attachment of the RE's onto the golf ball surface is robust and withstands the high impact forces and ball compression during a golf shot. Alternatively, retroreflective areas may be directly fabricated or painted on the

surface of a golf ball and individual areas may occupy more than one dimple. In the arrangement depicted in FIG. 8, 12 RE's occupy spherically symmetrical positions on the facets a golf ball with a regular dodecahedron dimple pattern. By this means, at least one RE is always within 30 degrees of direct view from any direction and can be easily detected by a DP. The RE's provide suitable reference marks from which the spin rate and spin axis of the ball can be detected using an array of DP's. Advantageously, this arrangement can be used to measure the spin rate and spin axis of the ball with any arbitrary initial orientation prior to impact. In alternative arrangements, 6 RE's may be positioned on the vertices of an octahedron pattern or 8 RE's on the facets of an octahedron or 20 RE's on the vertices of a dodecahedron or 20 RE's on the facets of an icosahedron and so on.

For optimum aerodynamic performance and conformance with the *Rules of Golf*, the dimple pattern on the surface of a golf ball must be spherically symmetric or very nearly so, with the surface pattern preferably repeating many times. For example a dodecahedron structure where the pattern repeats 12 times is superior to an octahedron structure where the pattern repeats only 8 times. However, in the dodecahedron structure exemplified in FIG. 8, the RE pattern in certain directions of view repeats for each 72 degrees of rotation. This can be disadvantageous as it is necessary to ensure that rotations that are more than 72 degrees or multiples of 72 degrees are correctly sensed. This can be arranged by ensuring that the DP's are sufficiently close across part of the ball trajectory to sense the highest expected rates of rotation with rotations of less than 72 degrees. Alternatively, the spherical symmetry of the RE pattern may be broken provided that the aerodynamic symmetry is maintained. To achieve this, the mechanical shape of an RE must closely emulate the shape and aerodynamic properties of other parts of the surface. If this can be achieved, the RE pattern can be asymmetric so that it only repeats for 180 or 360 degrees of revolution, but the surface pattern is aerodynamically symmetric.

The methods described above can equally well be applied to the scenario of a spot kick on a soccer ball or rugby ball to measure the resultant velocity and spin components. Since a soccer ball has much greater surface area than a golf ball, numerous RE's or larger, specially shaped RE's can be provided on the ball.

FIG. 9 is the plan view of an alternative ball launch analyser where the velocity vectors and certain orientations and positions of a club head 190 are sensed prior to impact with a golf ball 191 and only the velocity vectors of the ball are sensed. A sensor enclosure 192 has a DP window face 193 generally parallel but offset from the golf swing and ball trajectory paths and provides a number of DP's 194 crossing the path of the club head and golf ball in the pre-impact and post impact region of a golf shot. The DP's comprise a mixture of normal, angled, narrow width and expanded width types to fully detect the approach direction (in azimuth and elevation), speed, dynamic loft and offset (in vertical and horizontal sense) of the club head 190 and the launch velocity vectors of the ball. This gives sufficient data to determine the spin vectors of the ball as well as its velocity vectors. From this, a prediction of the subsequent ball flight can be made. Errors in measurement will degrade the accuracy of the flight prediction, but these errors are mainly systematic, especially if known types of club and a known type of ball are used. It is thus possible to correct systematic errors by applying feedback of the actual flight outcome measured by accurate means.

FIG. 10 shows a side view of the club head 190 and ball 191 as 'seen' by the DP array. The motion of the club head is sensed by tracking three RE's in the form of small, circular, retro-reflective dots, 195, 196 and 197 attached to the club head. The positions of the centre-planes of three DP's are shown by dotted lines 198, 199 & 200, where the planes are normal to the page in FIG. 10. The diameter of the RE dots are preferably nearly the same as the width of the DP's so that the signal pulse generated when a RE dot passes through a DP has a well defined peak. By this means the point in time when the dot is exactly central in a DP can be accurately estimated. The diameter of the RE dots may however be larger or smaller than the DP widths. Larger dots give higher signal magnitude but have flatter peak waveforms (though good estimation of the centre of the peak is still possible) and can be less convenient to attach to the club head.

The contrast of the RE's 195, 196 and 197 against reflections from the body of the club head can be enhanced by using filters to polarise the transmitted light from each TXRX pair in one direction and a second filter (for each TXRX pair) to polarise the received light at 90 degrees to the emitted light. In one possible arrangement, the ambient signal amplitude is measured just before and/or

just after a (pulsed) light emission and the reflected plus ambient signal amplitude is measured during the TXRX pulsed emission. Since these two measurements (or three measurements in the case of measurement before and after the pulsed emission) occur at nearly the same time so the club head position and orientation change very little during these measurements, the amplitude response to light reflected exclusively from the RE's can be found very precisely (assuming the above polarising filtering arrangement removes most of the unwanted reflections). In general, it is preferred to use infrared TXRX pairs as these generate light outside the visible spectrum, but other light wavelengths such as visible red light may be preferable since polarising filters are more readily available at these wavelengths.. If necessary, a mixture of light wavelengths can be used to eliminate visible disturbance prior to impact and enhance performance during the impact phase only. Also, the club head body can be sprayed with non-reflective coating prior to attaching its RE.

FIG. 11 shows the time dependant amplitude waveforms of the three RE's of FIG. 10 as they pass through the three DP's. The three waveforms each contain three pulses. In waveform 201, consecutive pulses 202, 203 and 204 correspond to the passage of the RE dots 195, 196 and 197 respectively through DP 198. In waveform 205, consecutive pulses 206, 207 and 208 correspond to the passage of the RE dots 195, 196 and 197 respectively through DP 199. DP's 198 and 199 are parallel and it can be seen that waveform 205 is a time-delayed replica of waveform 201. The speed of the club head can be found the duration of the time delay and the distance between DP's 198 and 199. In waveform 209, pulses 210, 211 and 212 correspond to the passage of the RE dots 195, 196 and 197 respectively through DP 200 but note in this case that pulse 211 precedes pulse 210 because, due to the inclination of DP 200 from the vertical, RE 196 is the first to pass through.

In FIG. 11, the waveforms are shown as continuous traces, but in practice it is preferable that the TXRX pairs are operated in pulse-multiplexed mode and the data is acquired as a sequence of digital samples (from a sampling analogue-to-digital converter). In one preferred but not limiting method of data analysis, the true centres of the pulses on the time axis are found by quadratic interpolation of three data points nearest each apparent peak to yield nine precise points in time (in the example of FIGS. 10 & 11), which are then used as input data in a mathematical model of

the DP's array and club head motion. A non-linear estimation such as the Levenberg-Marquardt method then extracts accurate swing parameters of the club head. Preferably, the centres of RE's 196 and 197 are positioned on a line parallel to the plane of the club face. This provides a datum from which the dynamic loft of the clubface can be found. (In the case of a wood type club head, it is preferable that the RE's on the toe are on a line perpendicular to the clubface.) The RE 195 is positioned on the neck or hosel in a known position relative to RE 197 and provides information on the dynamic lie and/or clubface angle.

In purpose-built clubs, the RE dots 195, 196 and 197 are preferably inserted into shallow circular recesses that are formed at manufacture. The exact location of the RE centres relative to the clubface are then known very accurately. It is also desirable to provide a similar RE arrangement on other makes of golf clubs. For example, RE dots 196 and 197 can be provided on a single strip of self-adhesive sticker, which is attached to the toe of the club head with the edge of the sticker aligned with the edge of the clubface as shown. This ensures that the centres of RE dots 196 and 197 are on a line parallel to the loft angle of the clubface. The self-adhesive sticker preferably forms a low reflectivity substrate to enhance the contrast of the RE dots. The RE 195 can also be mounted on a low reflectivity sticker. The position of RE 195 is less critical as its chief purpose is to provide an approximate indication of lie angle (i.e. the amount by which the heel-toe axis tilts relative to the horizontal). For wood clubs, the self-adhesive sticker 213 is attached to the toe and aligned along a perpendicular to the loft angle. The RE dots are typically all the same nominal size, but a mixture of different sizes can be used to provide a code to differentiate between different club head characteristics.

FIGS. 12(a) and 12(b) show two arrangements of buried loops that may be used to detect and locate a golf ball containing a RFID tag on a target area. The tags may be passive (i.e. have no internal power) or may be active, with power derived from a charged capacitor or the like. In the case of active tags, the operating range is greater and the tag can be powered-down once its data has been acquired.

FIG. 12 (a) shows an array of elongate, rectangular loops 301, 302 and 303 set at right angles to a second array of rectangular loops 304, 305 and 306. A golf ball with embedded RFID tag 307 is at rest and adjacent to loops 301 and 305. Each loop is connected to one channel in a multi-channel RFID reader 308. The reader 308 comprises a plurality of receiving channels but only one transmitting and interrogation sub-system. The reader 308 is initially in listening mode and waits until it receives a wake-up signal from the RFID tag 307. The tag 307 is programmed to transmit this wake-up signal every two to three seconds or so. On reception of the wake-up signal, the reader 308 selects the two channels connected to orthogonal loops that have the strongest signal reception (i.e. loops 301 and 305 in the case illustrated) and uses at least one of these channels to interrogate the tag and identify the tag code. By this means the golf ball is known to be in the vicinity of the overlap of loops 301 and 305 and its code is identified. The arrangement of FIG. 12 (a) can be extended to a greater number of loops, or fewer loops can be used. The loops can be rectilinear as at 301 to 306 or may be in a coiled configuration as shown at 309.

FIG12 (b) shows an alternative arrangement of a two long loops 310 and 311 that are spiral wound to fit into a circular area. This is especially useful for detecting balls within a radial distance of a flag at the centre of a target area (not shown). The arrangement may be extended to third or fourth loops (and so on) to detect balls at different radial distances from the flag. An advantage of the loop configurations of 309, 310 and 311 is that they do not form efficient antennas for far field radiation but do have strong near field radiation. To improve the reliability of tag identification, two or more antennas or loop arrangements may be provided in the same sensing are but offset or orthogonal to each other such that voids in receptivity do not occur. On receiving a wake-up signal from a stationary tag, the channel with best radio reception is selected to communicate with that tag. In an alternative arrangement, the embedded tag in a golf ball may itself contain two or three mutually orthogonal antennas.

In an alternative system, only the landing position and flight duration of driven balls are measured using (for example) geophones to detect vibrations in the ground in the vicinity of a target area. Only four geophones are required to determine the landing distance and deviation co-ordinates of a ball. In this case, the launch parameters are used to predict only the flight of the ball. For balls

that do not land within detection range of the target area, the carry and deviation of each ball is computed by interpolation of results for balls that did previously land in range of a target, using the computer prediction of ball flight. The measurement of ball position in range of a target area need not be highly accurate (i.e. ±0.5 metre is sufficient) but it is very important to correctly measure the rare event of a ball rolling or flying into a cup (i.e. the standard 4.25 inch hole of a golf green). In golf, this event is referred to as a 'hole in one' and is often rewarded by prize money or the like. In this case it is useful to have a passive RFID tag on each ball and a RFID reader on each cup or hole provided on the range (usually positioned in the centre of each target area) so that any golfer who achieves the 'hole in one' shot is properly identified.

In a further arrangement, the target area may comprise or include a 'built target' constructed from panels in a concentric and/or radial configuration, with one or more vibration sensors attached to each panel to detect impact of a ball. By this means the ball landing spot can be sharply delineated into different concentric circles and/or different quadrants or the like. Preferably, the panels form a cone or dome, so that balls landing on any part of the built target usually bounce away from, but very rarely bounce back onto, the built target. This ensures that any ball hitting a built target generates a single unambiguous impact signal. Alternatively, the panels may be constructed so as to highly dampen the impact of the ball so that subsequent bounces are very weak compared to the first landing impact. This second method is useful if the built target is used in conjunction with a geophone array to measure landing impacts on the ground surrounding the built target.

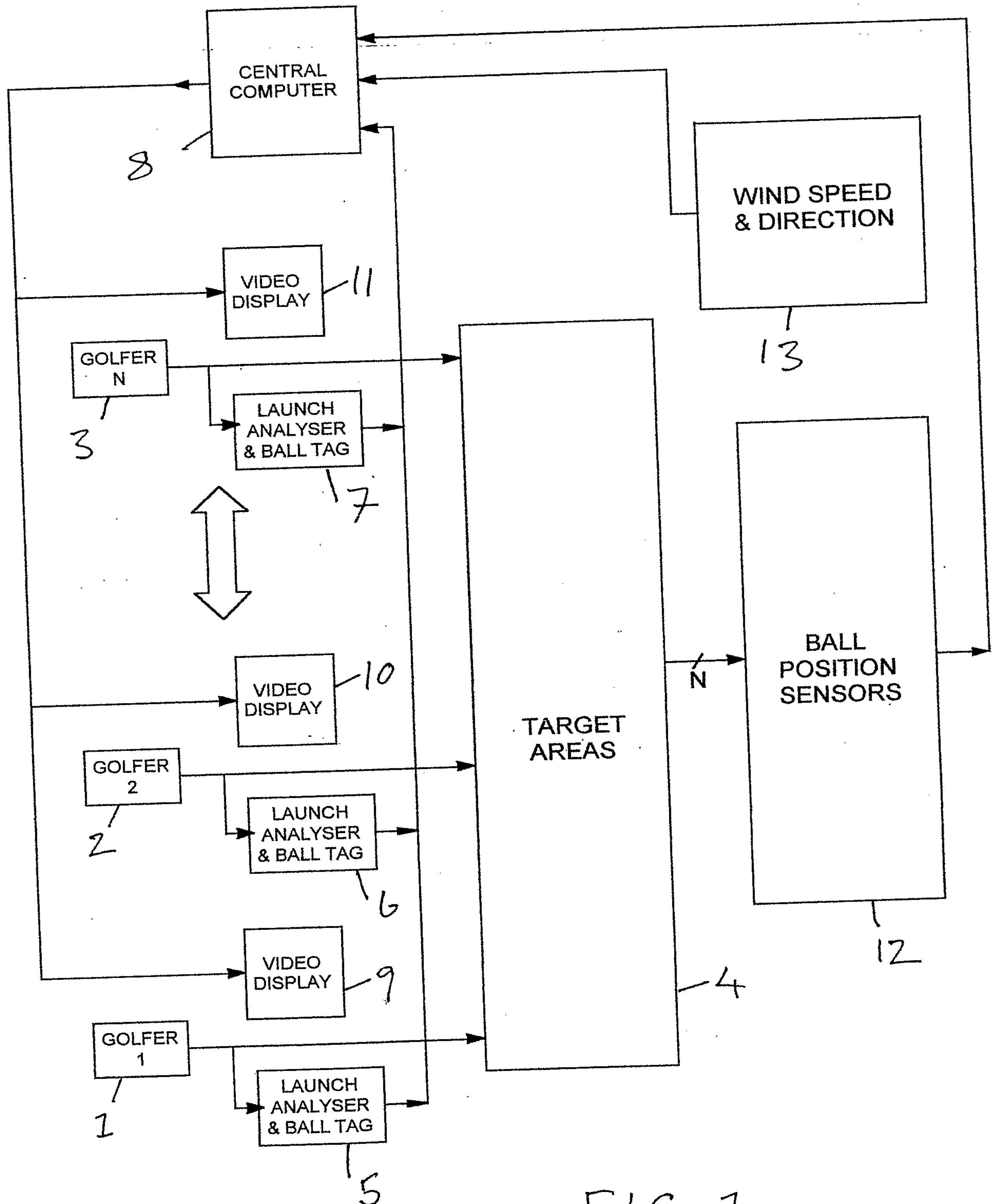
CENTRAL COMPUTER
8
WIND SPEED & DIRECTION
13
VIDEO DISPLAY
11
GOLFER N
3
LAUNCH ANALYSER & BALL TAG
17
VIDEO DISPLAY
10
TARGET AREAS
N
BALL POSITION SENSORS
GOLFER 2
2
LAUNCH ANALYSER & BALL TAG
6
12
VIDEO DISPLAY
9
4
GOLFER 1
1
LAUNCH ANALYSER & BALL TAG
5

FIG. 1

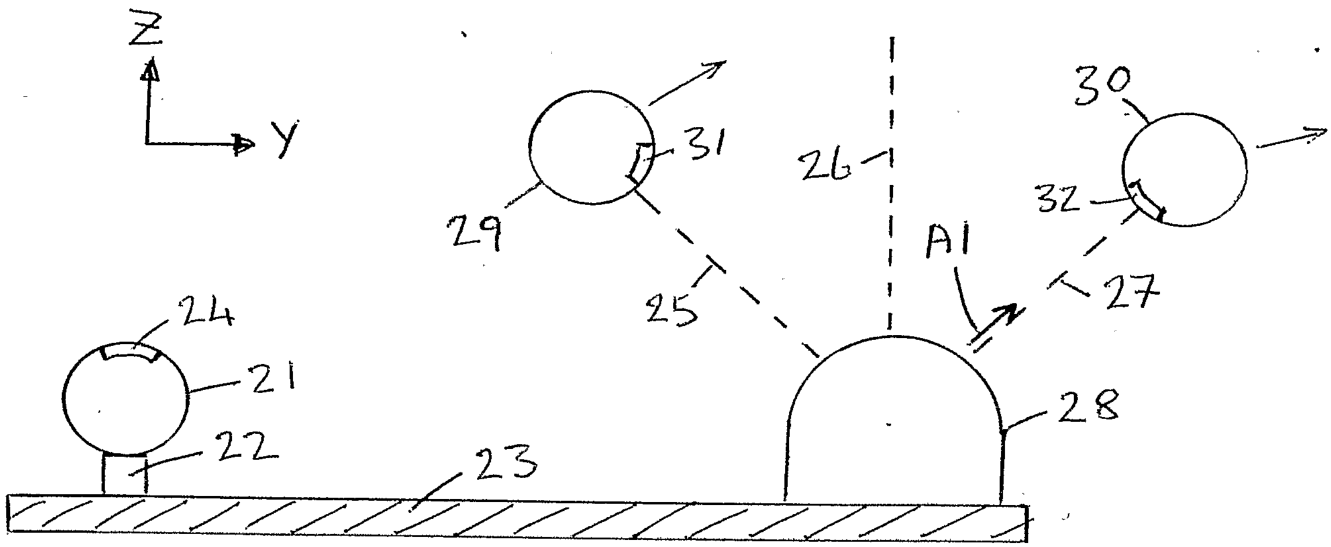

FIG. 2

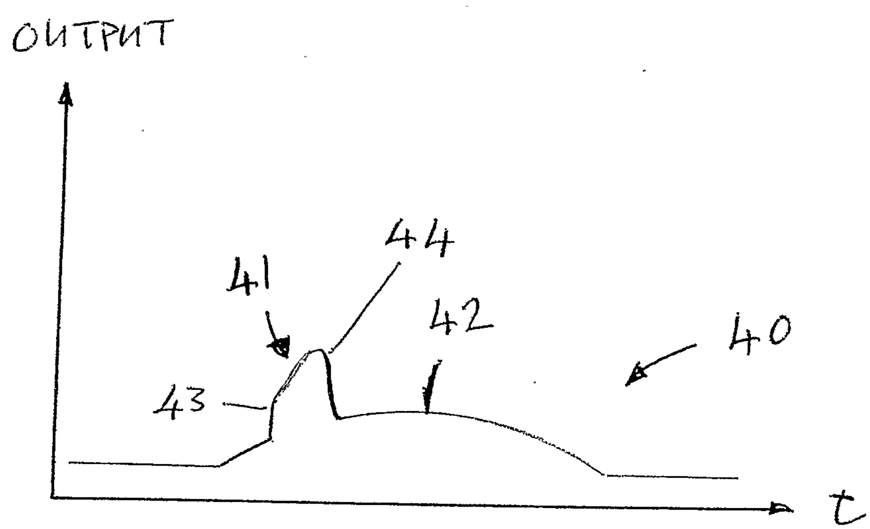

FIG. 3

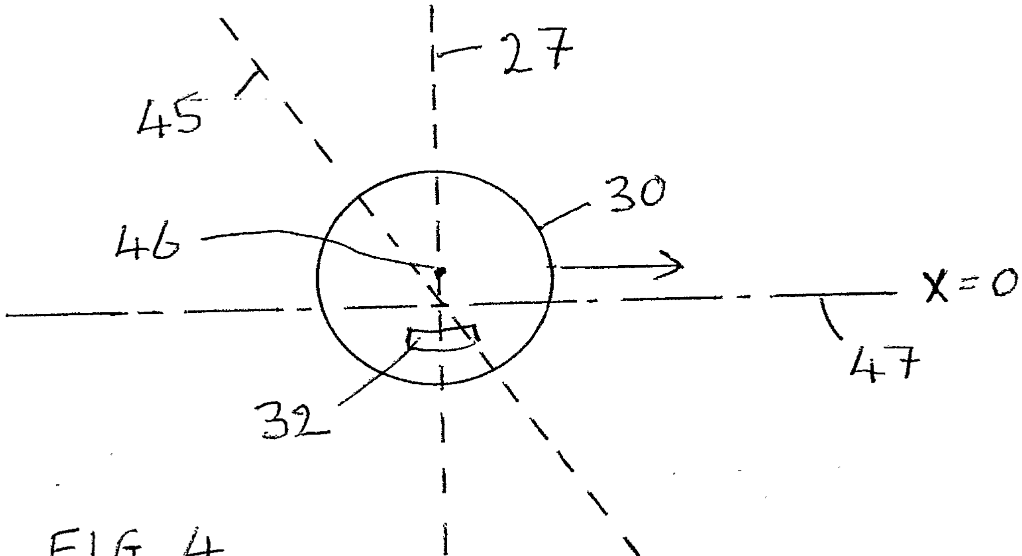

FIG. 4

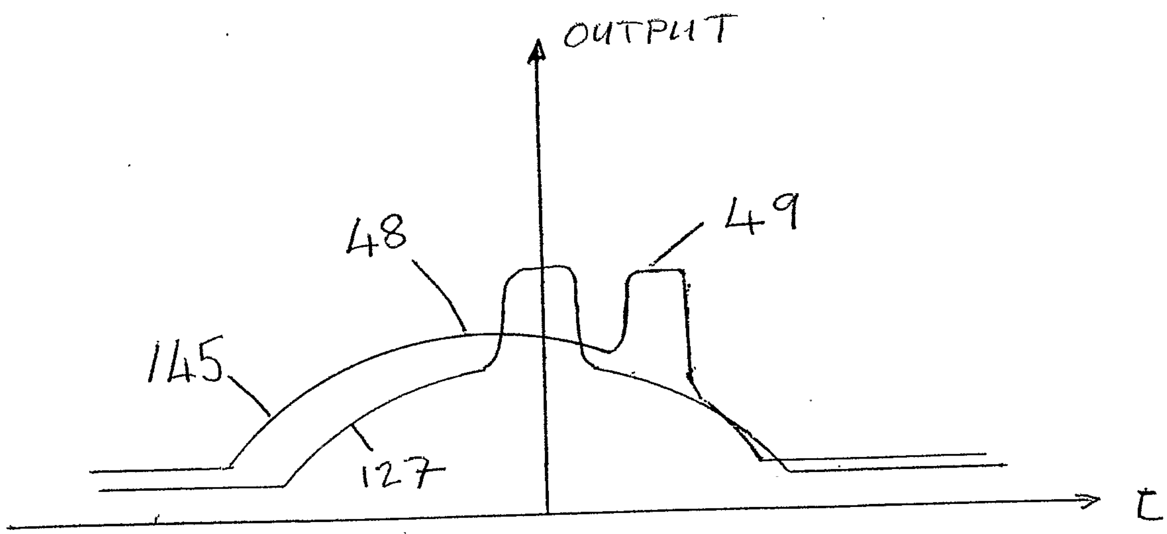

FIG. 5

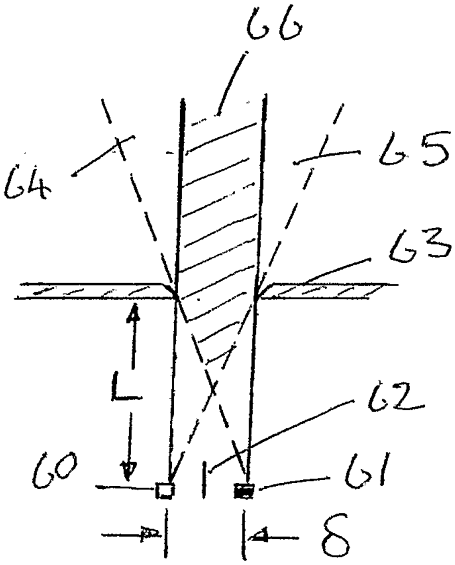

FIG. 6(a)

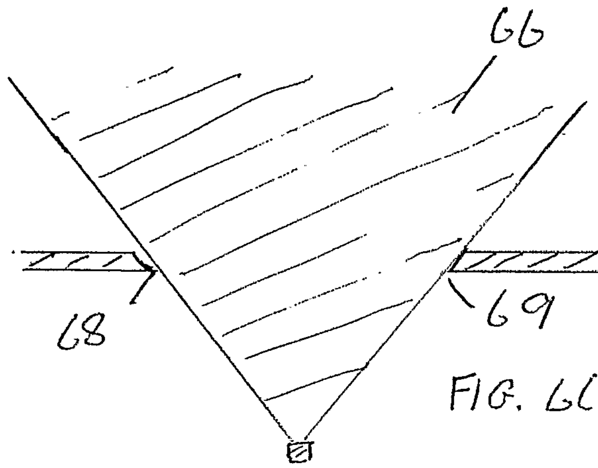

FIG. 6(b)

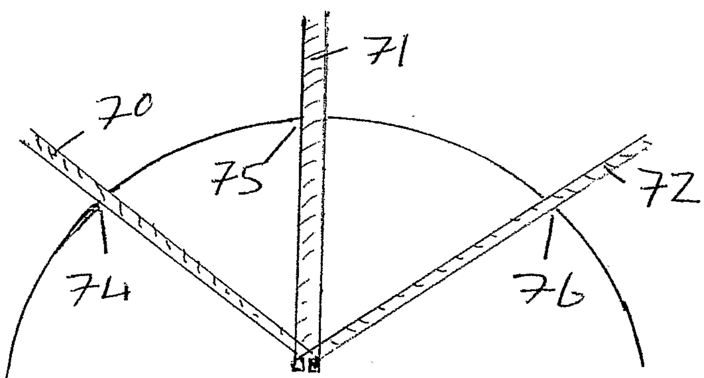

FIG. 6(c)

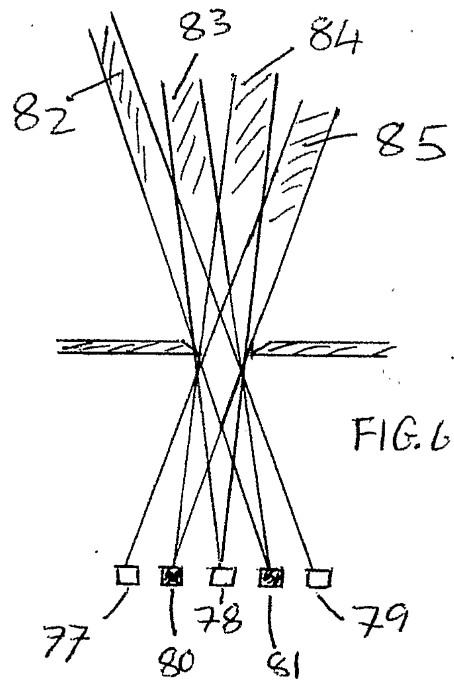

FIG. 6(d)

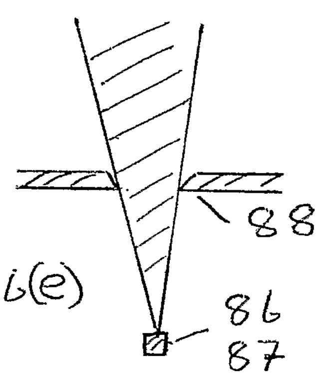

FIG. 6(e)

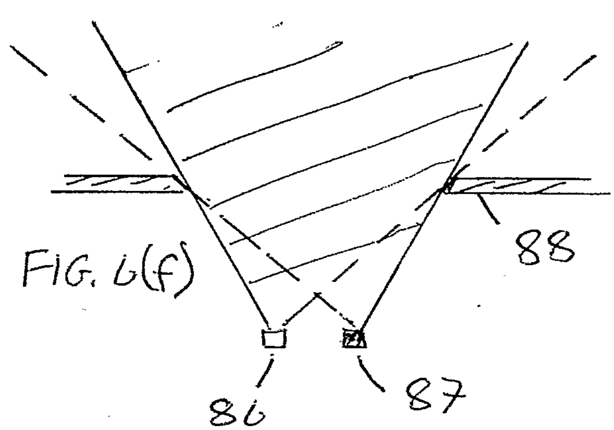

FIG. 6(f)

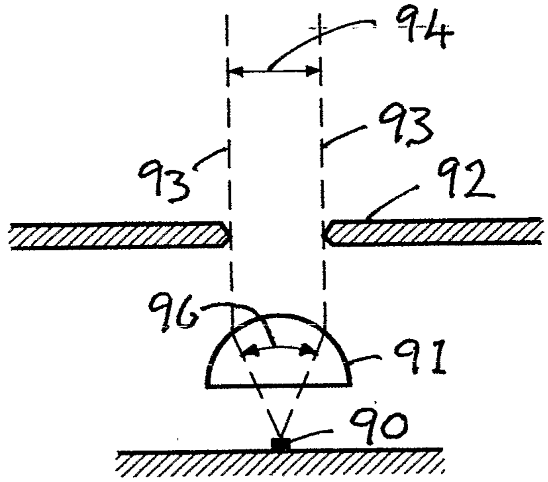

FIG. 7(a)

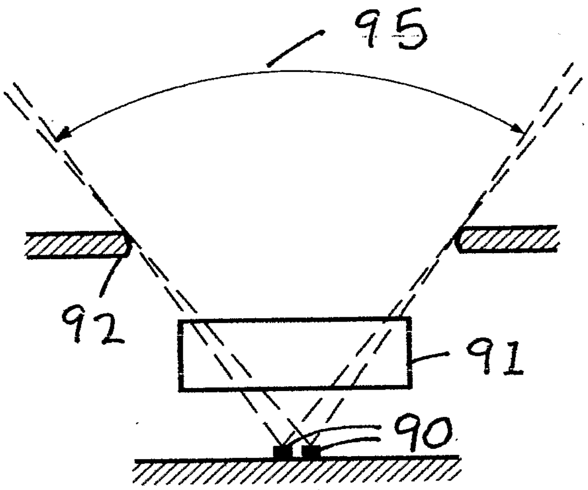

FIG. 7(b)

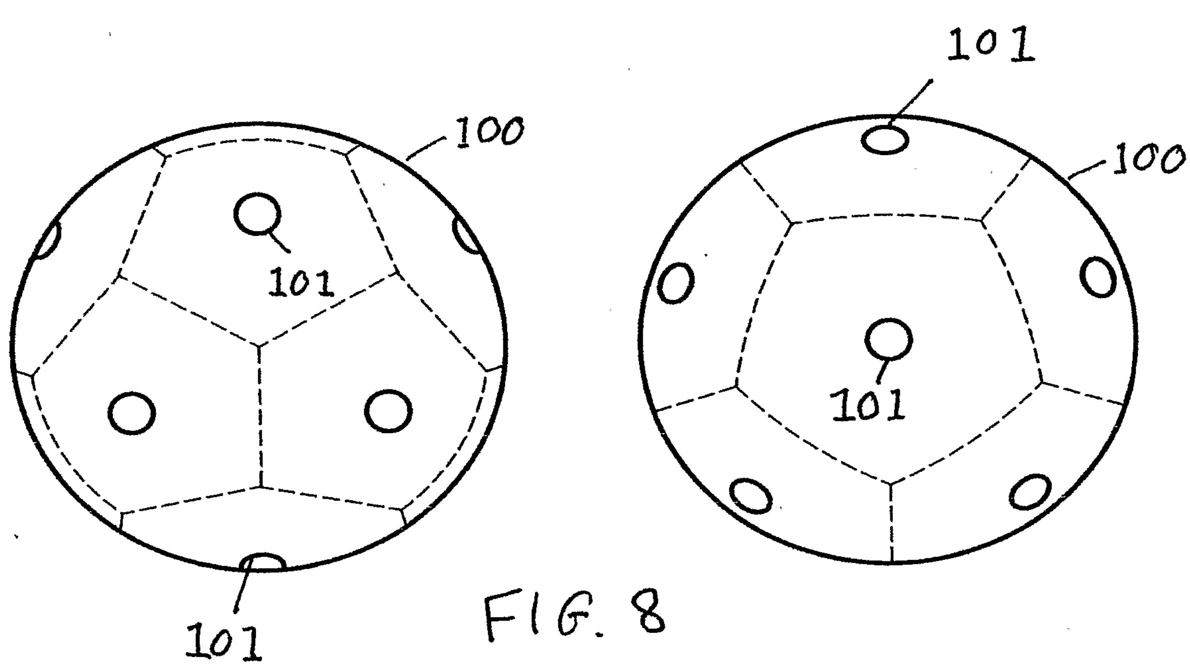

FIG. 8

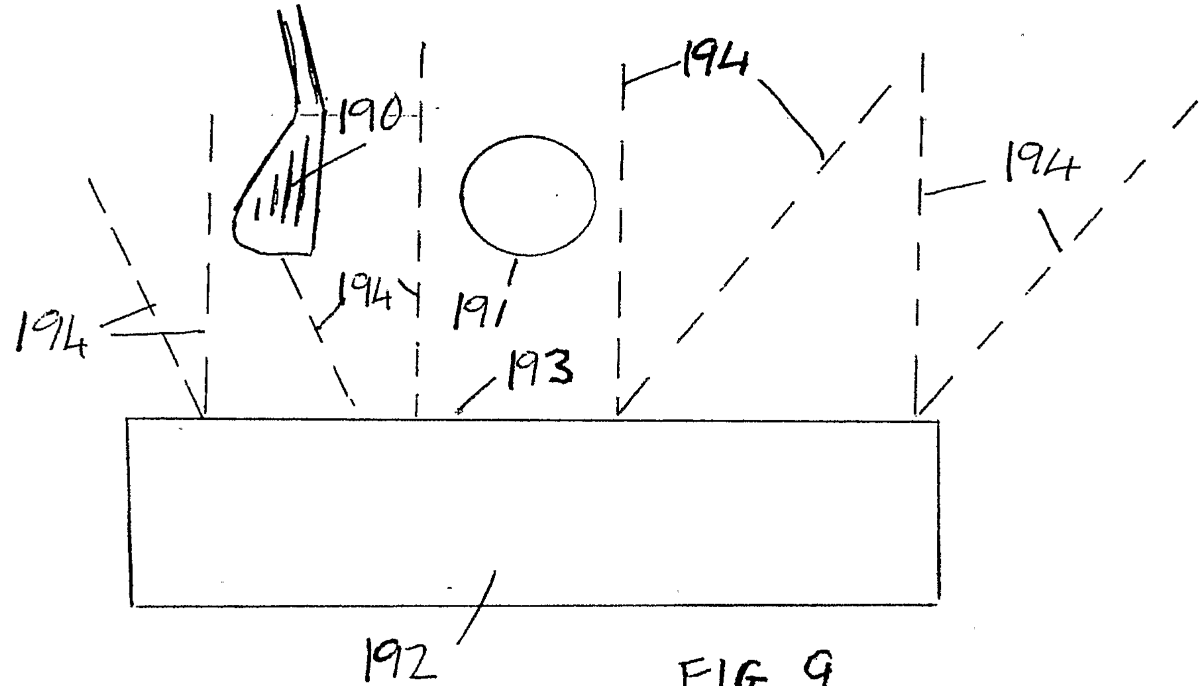

FIG. 9

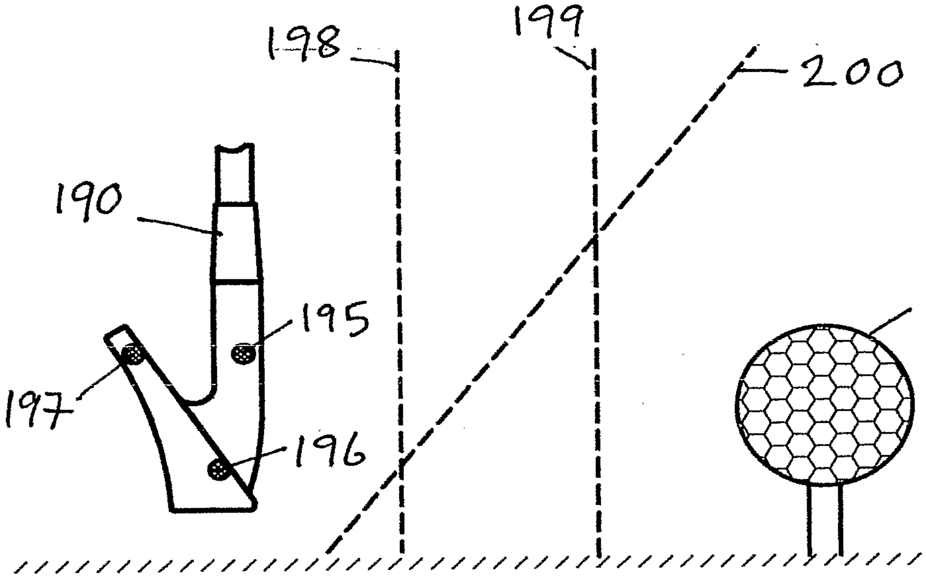
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FIG. 10

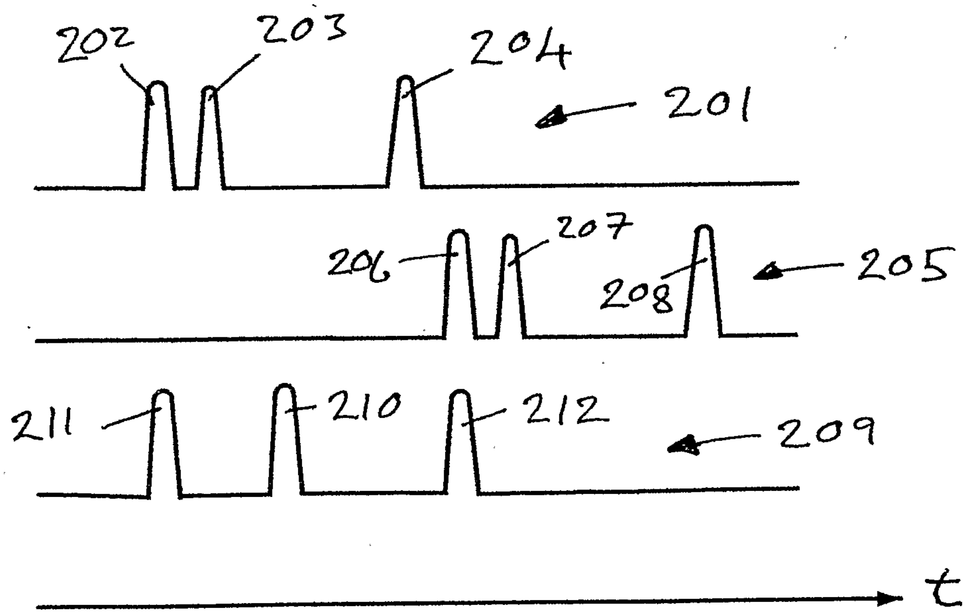
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FIG. 11

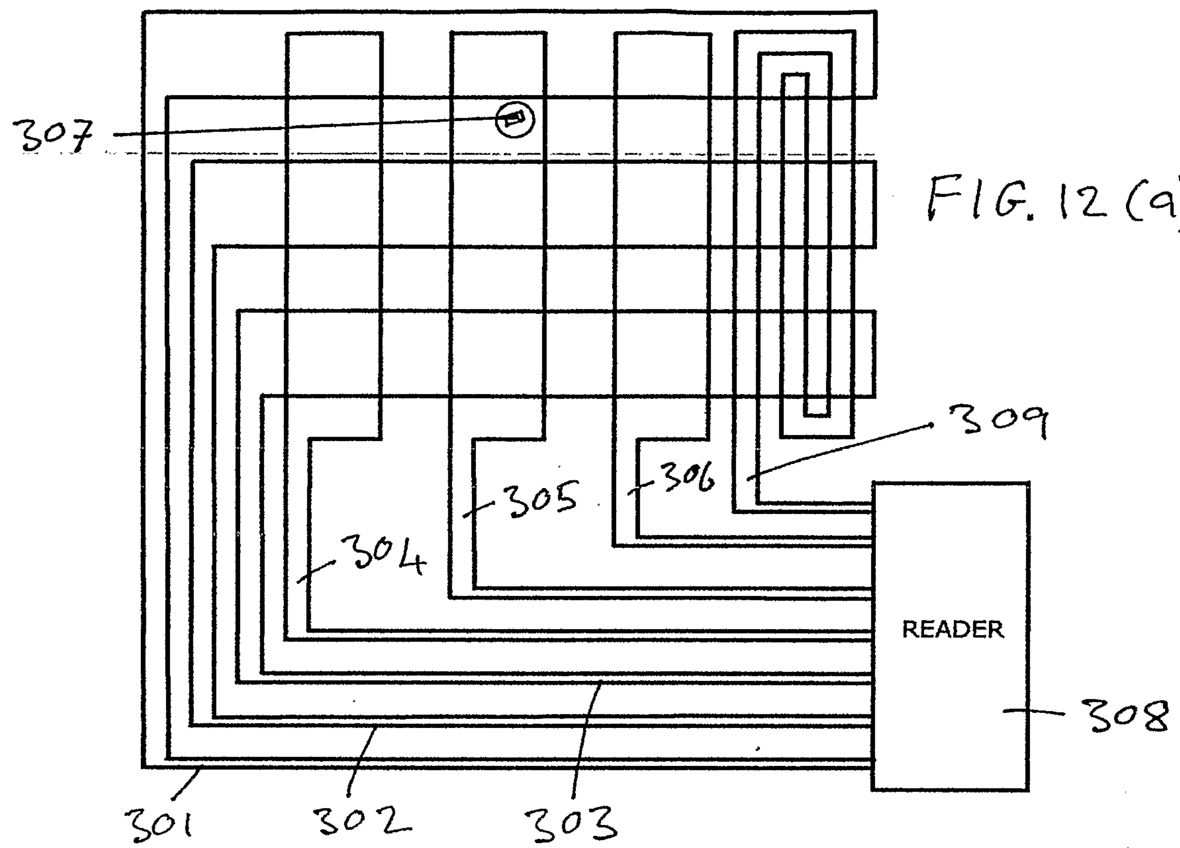

FIG. 12 (a)

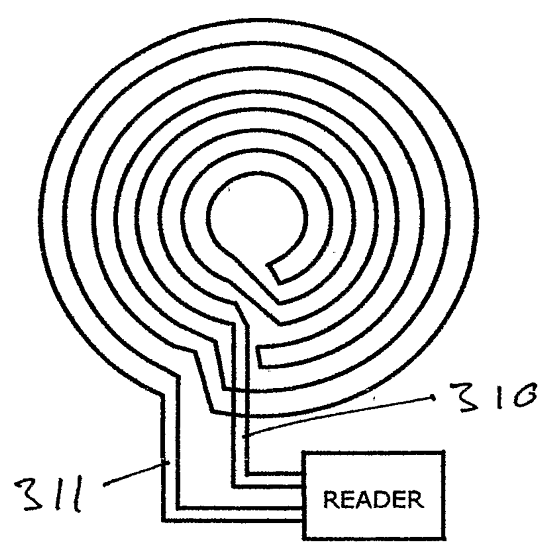

FIG. 12 (b)